

Electrical Short Circuit and Current Overload Tests on Aircraft Wiring

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| 16. Abstract This document describes the electrical short circuit and current overload tests that were conducted on wires used in commercial transport category aircraft. This testing was conducted to evaluate the fire potential that may result from electrical faults. Results of this testing showed that circuit breakers provide reliable overcurrent protection and that circuit breakers may not protect wire from ticking faults but can protect wire from direct shorts. It also showed that circuit breakers may not safeguard against the ignition of flammable materials by ticking faults. Preliminary testing also indicated that direct short circuits are not likely to start a fire and that direct short circuits do not erode insulation and conductors to the same degree that ticking faults do. Current overload testing that resulted in complete thermal degradation of the wire was also conducted to compare it with a fire-exposed wire. No differences were seen; however, the conductor of the wire subjected to the fire was more brittle than the current overloaded wire. Further testing along with metallurgical evaluation would be necessary to substantiate this finding fully. | | | | | |
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LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|------|---|
| amp | Ampere |
| APU | Auxiliary Power Unit |
| AWG | American Wire Gauge |
| DoD | Department of Defense |
| ETFE | Ethylene-Tetrafluoroethylene |
| FAA | Federal Aviation Administration |
| IEC | International Electrotechnical Commission |
| kVA | Kilo Volt Ampere (s) |
| PTFE | Polytetrafluoroethylene |
| RMS | Root Mean Square |
| UL | Underwriters Laboratories Incorporated |
| V | Volts |

1. INTRODUCTION.

1.1 PURPOSE.

The purpose of this report is to present the findings of electrical short circuit and current overload tests performed on commercial aircraft wiring.

1.2 BACKGROUND.

The fire potential resulting from electrical faults on transport category aircraft is illustrated by three fires that have occurred during the past several years. A description of each follows:

On January 18, 1990, a USAir MD-80, en route to Cleveland from Buffalo, was forced to return to Buffalo when the cockpit filled with smoke from overheated electrical wire insulation. The left generator tripped off-line and the captain turned the right generator control switch to the "Off" position. He selected emergency power and initially was able to clear the smoke. The captain then started the auxiliary power unit (APU) and the cockpit again started to fill with smoke. The APU electrical power was then shut off and the emergency electrical power was turned back on. The aircraft returned to Buffalo with no further reports of smoke. It was found that the left generator phase B power feeder cable terminal, which is connected to a plastic terminal strip, had melted from intense arcing. The terminal, approximately 15 inches of the cable, and the terminal stud had melted. The second source of smoke came from a fire started by the molten metal that sprayed an area forward of, and below the terminal strip. The only circuit breaker to trip was the cabin temperature control. This incident was caused by improper torquing of the phase B terminal.

On March 17, 1991, a Delta L-1011 en route from Frankfurt, Germany, to Atlanta, Georgia, was forced to make an unscheduled landing in Goose Bay, Labrador, Canada. About 7.5 hours into the flight, flames erupted from the base of the left cabin sidewall panel to the height of the seatback tray at the next to last row of passenger seats. The fire was extinguished and a precautionary landing was made. The ignition source of this fire was not determined; however, a possible source of ignition appeared to be an electrical fault. Some of the wires in a fifteen wire bundle located in the fire area exhibited evidence of arcing. Five circuit breakers connected to this wire bundle had tripped.

On November 24, 1993, an SAS MD-87 experienced smoke and a subsequent fire upon touchdown. The fire damage was severe, including a 1-foot-diameter hole through the fuselage skin. Investigation found that two wires, one 115 volts (V) and one 28V, had been pinched together and were arcing to the fuselage structure. Neither the 10-ampere (amp) circuit breaker (28V line) nor the 15-amp circuit breaker (115V line) tripped.

It is apparent from these three incidents that certain questions present themselves:

- a. Are ticking faults more likely to start a fire than the hard direct short?
- b. Do circuit breakers provide adequate protection?
- c. Is there anything definitive an investigator can look for to help determine if electrical failure was the cause?

2. DESCRIPTION OF TESTS AND RESULTS.

2.1 CURRENT OVERLOAD TESTS.

A series of bench-scale tests were conducted to evaluate circuit breaker response to overcurrent and to determine if the wire showed any visible signs of thermal degradation due to overcurrent. Three types of wire used in commercial aircraft were evaluated:

- a. MIL-W-22759/34 150°C (302°F) rated
- b. MIL-W-81381/12 200°C (392°F) rated
- c. BMS 1360 260°C (500°F) rated (hybrid construction)

All wires were 20 American Wire Gauge (AWG). This gauge was chosen because it is one of the most commonly used sizes. In this test, a 7.5-, 10-, and a 15-amp circuit breaker (all standard aircraft thermal breakers) were subjected to 135 percent of their current rating and time-monitored when the breaker tripped. All tests were conducted at room temperature (23°C, 73°F). Figure 1 shows a diagram of the test circuit. Each wire segment rested on thermal/acoustic insulation (fiber glass with polyester film cover). This test, which is a calibration test used by circuit breaker manufacturers, references the International Electrotechnical Commission (IEC) 934, Circuit Breakers for Equipment, and the Underwriters Laboratories Incorporated (UL) 1077, Supplementary Protectors for use in Electrical Equipment. This test calls for wire rated at 600V and 105°C (221°F). The following is a section of the wire gauge table derived from IEC 934 for this test:

| Amp Rating | AWG |
|----------------|-----|
| < than 1 | 20 |
| 1 through 6 | 18 |
| >6 through 13 | 16 |
| >13 through 20 | 14 |

The circuit breaker rating (in amps) and allowable wire gauge used in commercial aircraft are different from those given above. The Federal Aviation Administration (FAA) approved electrical wire charts and tables specify 20 AWG wire to carry a maximum current of 7.5 amps in conduit or bundled and 11 amps in free air. This is because the temperature ratings of transport

category aircraft wiring are much higher than the 105°C (221°F) wire specified in the above test method. The use of a 7.5-amp circuit breaker to protect 20 AWG wire was based on aerospace industry testing and computer modeling. This breaker and wire size are also specified in MIL-W-5088 Wiring, Aerospace Vehicle. This specification is approved for use by all departments and agencies of the Department of Defense (DoD). While a 10- and 15-amp circuit breaker would not be used to protect 20 AWG aircraft wiring, this size was selected for testing to determine if any thermal degradation of the insulation occurred that would be apparent or verifiable by microscopic techniques as a result of an overload situation. Table 1 gives the results. The data show that all the breakers tripped well within the one-hour time frame specified in this test method. The wires tested were examined and then cut open to inspect the conductor and other layers of insulation, if applicable, by microscope. There were no signs of degradation internally or externally due to heat such as discoloration, warpage, or embrittlement; and the thermal/acoustic installation showed no signs of heat damage.

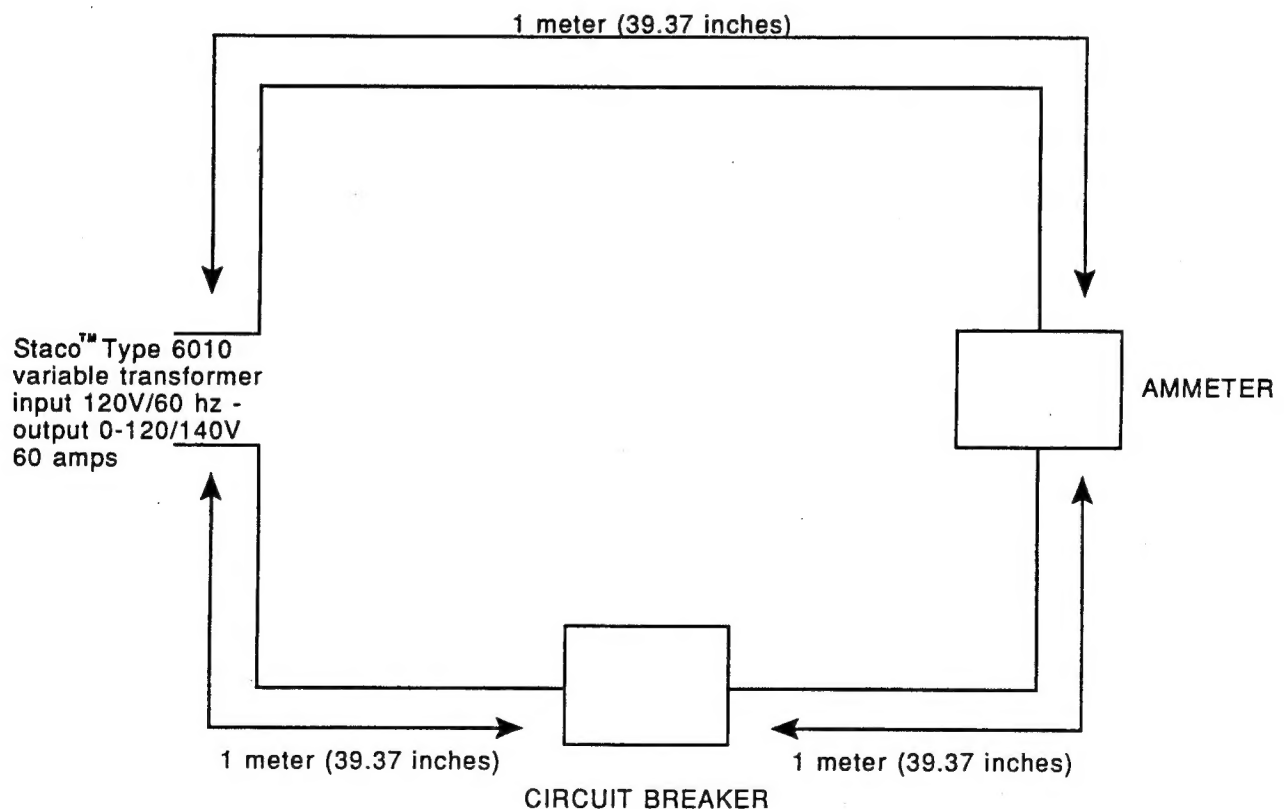


FIGURE 1. TEST CIRCUIT

TABLE 1. OVERCURRENT DATA

| Wire Type | Circuit Breaker Rating | 135 Percent Current Rating | Time to Trip |
|----------------|------------------------|----------------------------|-----------------------|
| MIL-W-81381/12 | 7.5 amps | 10.1 amps | 2 minutes 10 seconds |
| MIL-W-22759/34 | 7.5 amps | 10.1 amps | 4 minutes 8 seconds |
| BMS 1360 | 7.5 amps | 10.1 amps | 3 minutes |
| MIL-W-81381/12 | 10 amps | 13.5 amps | 8 minutes 30 seconds |
| MIL-W-22759/34 | 10 amps | 13.5 amps | 16 minutes |
| BMS 1360 | 10 amps | 13.5 amps | 11 minutes 40 seconds |
| MIL-W-81381/12 | 15 amps | 20.2 amps | 6 minutes 20 seconds |
| MIL-W-22759/34 | 15 amps | 20.2 amps | 2 minutes 45 seconds |
| BMS 1360 | 15 amps | 20.2 amps | 5 minutes 5 seconds |

2.2 RESULTS OF CURRENT OVERLOAD TESTING VS. FIRE-EXPOSED WIRES.

Each of the three test wires was then subjected to current overload without a circuit breaker in-line. Three feet of each wire type (20 AWG) was connected to a variable transformer and placed on thermal/acoustic insulation with polyester film cover. The current for each wire type was determined by previous testing to cause complete thermal degradation of the wires.

These tests were run for approximately 12 minutes to compare them with the same type of wires subjected to fire for approximately 12 minutes. The values are as follows:

| | | |
|----------------|-------|---------|
| MIL-W-81381/12 | 9.6V | 41 amps |
| MIL-W-22759/34 | 7.2V | 33 amps |
| BMS 1360 | 10.8V | 51 amps |

The thermal/acoustic insulation was charred where the wire rested, and the polyester film smoked and shrunk. Ignition of the polyester film occurred in some areas. Each wire was compared to a wire of the same type which had been placed in a cardboard box with paper shavings and ignited. The duration of this fire was approximately 12 minutes at 982°C (1800°F).

In comparing the BMS 1360 and the MIL-W-81381/12 wires subjected to overcurrent with those subjected to the fire, no visible differences were detected. The charred remains of the wrapped films were present. The MIL-W-22759/34 wire subjected to the overcurrent also looked the same as the MIL-W-22759/34 wire exposed to the fire. The insulation material was consumed in both cases, exposing the tin-plated conductor. The common denominator found for all three wire types was the brittleness of the conductor. By flexing the cables, it was found that the wires that were subjected to the fire were more brittle than those exposed to the overcurrent.

2.3 SHORT CIRCUIT TESTING.

In this series of bench-scale tests, circuit breaker response to short circuits and ticking faults was evaluated. These tests were also meant to determine if the three test wires behaved differently under the above conditions and if a short circuit or ticking fault could start a fire.

Two wires, each three feet long, were connected to a 220V/115V 400-cycle, three-phase generator rated at 18.75 kilo volt amps (kVA); one wire was connected to a "leg" of the wye connection; and one wire was connected to the neutral. This configuration results in a 115V potential (single-phase power) between the two wires. A 7.5-amp aircraft circuit breaker rated at 500 amps of interrupting current at 120V AC-400 Hz was in-line with the "hot" leg. Each of the wires had approximately 1/2 inch of insulation stripped from their ends, and the wire strands were twisted together and suspended vertically with the stripped ends separated approximately one inch. A piece of non fire-retarded polyurethane foam was then placed approximately 1/4 inch behind the two wires. Using a wooden grasping device, the two wires touched intermittently (ticking faults). They were also brought and held together to cause a direct short circuit. This same test was repeated using 208V (phase-to-phase) with a 7.5-amp circuit breaker protecting each leg. Tables 2 and 3 summarize the test results.

The data indicates that the circuit breakers did not protect the wire against ticking faults in both the 115V and 208V testing. In each case, the temperature generated by the arcs during each successive ticking fault ignited the nearby materials. Therefore, the minimal duration of metal-to-metal contact (time factor) along with the limited *current* due to the "instantaneous" arc would explain why the circuit breakers did not trip.

In all the 115V and 208V tests the circuit breakers protected the wire against direct shorts. While sparks were observed as the two conductors were brought together, fusion occurred almost instantaneously, resulting in the circuit breaker tripping. The data show that there was no ignition of the foam during any test. While the current might have been very high (hundreds or thousands of amps), the voltage was low. Therefore, available power was small ($P = EI$).

These tests did not evaluate the effects of molten metal (pieces of conductor which spewed forth during some ticking faults) as ignition sources. It is likely, however, that they could ignite a flammable material upon impingement, as was the case in the MD-80 fire discussed earlier in this report.

2.4 APPEARANCE OF CONDUCTORS.

In all the 115V and 208V cases, fusion of the conductors occurred upon direct short-circuit testing. (Remembering that a 20 AWG conductor is composed of 19 strands of wire, fusion in this case does not imply that each strand of each conductor melted and joined.) Fusion in this testing implies that any number of strands fused, resulting in a complete short circuit that tripped the breaker. No "bead" formation occurred during this testing; however, there were discrete

areas of melted conductor which appeared layered. The insulation materials showed no effect from the "heat" of fusion; however, they were slightly warm.

In some instances, the wires in the ticking fault testing (115V and 208V) showed weld formation on discrete areas of both conductors. These welds were not formed due to the fires but from the heat generated during ticking fault testing. Some of the strands in each of the two wires fused together and appeared dull in color. During one 208V test, the exposed conductors vaporized up to the insulation material after the third ticking fault. Since the fires propagated up the foam, very little wire insulation was subjected to the fire. There was some scorching and soot on the insulation materials that were briefly subjected to the fire.

TABLE 2. 115 VOLT TEST DATA

| Wire Type | Ticking Faults | Circuit Breaker Tripped | Notes |
|----------------|----------------|-------------------------|---|
| MIL-W-81381/12 | 6 | No | Sparks, some arcing, on sixth fault severe arcing ignited the foam and totally consumed it, "Beads" on the ends of both conductors, approximately 3/16 to 4/16 inch of conductor left |
| MIL-W-22759/34 | 5 | No | Sparks, some arcing, on fifth fault severe arcing ignited the foam and totally consumed it, "Beads" on the ends of both conductors, approximately 3/16 to 4/16 inch of conductor left |
| BMS 1360 | 5 | No | Sparks, some arcing, on fifth fault severe arcing ignited the foam and totally consumed it, "Beads" on the ends of both conductors, approximately 3/16 to 4/16 inch of conductor left |
| Wire Type | Direct Short | Circuit Breaker Tripped | Notes |
| MIL-W-81381/12 | 1 | Yes | Sparks (spit), fusion of the two conductors |
| MIL-W-22759/34 | 1 | Yes | Sparks, fusion of the two conductors |
| BMS 1360 | 1 | Yes | Sparks, fusion of the two conductors |

TABLE 3. 208 VOLT TEST DATA

| Wire Type | Ticking Faults | Circuit Breaker Tripped | Notes |
|----------------|----------------|---|---|
| MIL-W-81381/12 | 3 | No | During the first fault most of the conductors vaporized leaving approximately 2 to 3/16 inch of conductor remaining , severe arcing, the foam ignited and was totally consumed during the third ticking fault, exposed conductors totally vaporized |
| MIL-W-22759/34 | 3 | 1. Yes, one breaker on first fault 2. No, on the third fault that ignited the foam | During the first fault, fusion occurred, cut and stripped both conductors, severe arcing, foam ignited and was totally consumed on third fault |
| BMS 1360 | 3 | No | Severe arcing, sparks, crater formed in foam, on third fault, foam ignited and was totally consumed |
| Wire Type | Direct Short | Circuit Breaker Tripped | Notes |
| MIL-W-81381/12 | 1 | Yes | Some sparks, conductors fused |
| MIL-W-22759/34 | 1 | Yes | Some sparks, conductors fused |
| BMS 1360 | 1 | Yes | Some sparks, conductors fused |

3. CONCLUSIONS.

1. Circuit breakers provided reliable overcurrent protection.
2. Circuit breakers may not protect wire from ticking faults but can protect wire from direct shorts.
3. These tests indicated that the appearance of a wire subjected to a current that totally degrades the insulation looks identical to a wire subjected to a fire; however, the "fire exposed" conductor was more brittle than the conductor degraded by overcurrent.
4. Preliminary testing indicates that direct short circuits are not likely to start a fire.
5. Preliminary testing indicated that direct short circuits do not erode insulation and conductor to the extent that ticking faults did.
6. Circuit breakers may not safeguard against the ignition of flammable materials by ticking faults.

7. The flammability of materials near ticking faults is far more important than the rating of the wire insulation material.

4. GLOSSARY.

ARC: A luminous discharge of electricity through a gas, and/or a prolonged electrical discharge or series of prolonged discharges between two electrodes (no physical contact between them).

CIRCUIT BREAKER: A device used to open and close a circuit by non-automatic means as well as to open a circuit automatically on predetermined overcurrent without damaging itself (when properly applied within its rating).

EFFECTIVE VOLTAGE (or CURRENT): Effective value of sinusoidal voltage or current is 0.707 times the peak value. Also designated root mean square (rms) value. With AC voltage, effective value is understood unless otherwise noted.

OVERCURRENT: In a circuit, the current that will cause an excessive or even dangerous rise in temperature in the conductor or its insulation.

PHASE-TO-PHASE: Voltage measured between two "corners" of a delta connection or between any two "legs" of a wye connection.

SHORT CIRCUIT: Also called a short. An abnormal connection of relatively low resistance between two points of a circuit. The result is a flow of excess (often damaging) current between these points.

SPARK: The discharge of electric current through air or another insulator. An electrical spark is virtually instantaneous.

TICKING FAULT: An intermittent metal-to-metal event (conductor-to-conductor, conductor-to-structure, etc.) that results in the discharge of sparks and arcing events.

WIRE DESCRIPTIONS:

BMS 1360: Composite insulation, polytetrafluoroethylene (PTFE) fluorocarbon, aromatic polyimide and an outer layer of PTFE. Normal weight, nickel-coated copper conductor.

MIL-W-22759/34: Crosslinked modified ethylene-tetrafluoroethylene copolymer (ETFE). Normal weight, tin-coated copper conductor.

MIL-W-81381/12: Fluorocarbon/aromatic polyimide insulated. Medium weight, nickel-coated copper conductor.